R-45

NBS REPORT

8838

SECOND QUARTERLY PROGRESS REPORT ON CRYOGENIC DATA CENTER ACTIVITIES FOR THE PERIOD ENDING JUNE 30, 1965

N65-87867
(ACCESSION NUMBER)
18
(PAGES)
CR-64514
(NASA CR OR TMX OR AD NUMBER)
(THRU)
None
(CODE)
(CATEGORY)
FACILITY FORM 602

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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NATIONAL BUREAU OF STANDARDS REPORT

NBS REPORT 8838

June 30, 1965

SECOND QUARTERLY PROGRESS REPORT ON CRYOGENIC DATA CENTER ACTIVITIES FOR THE PERIOD ENDING JUNE 30, 1965

V. J. Johnson
R. B. Stewart
N. A. Olien

NBS PROJECT	SPONSORING AGENCY	CONTRACT DESIGNATION
315-40-3150121	NBS-CD	
315-40-3150420	NASA-SNPO	NASA Order R-45
315-40-3150421	NBS-NSRDS	
315-40-3150422	NASA-MSFC	Government Order H-76797

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NATIONAL BUREAU OF STANDARDS

N O T I C E

The report on NBS Project 3150420 (see Section 3.0) was prepared under NASA Order R-45, entitled, "Investigations and Studies of Liquid Hydrogen and Other Cryogenic Fluids", for the Office of Research Grants and Contracts of the National Aeronautics and Space Administration. The work is administered under the technical direction of the Space Nuclear Propulsion Office, Lewis Research Center, with Dr. Landon Nichols as project manager

The report on NBS Project 3150422 (see Section 5.0) was prepared under Government Order H-76797, entitled, "Cryogenic Propellant Fluid Properties Data Evaluation Program", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work is administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the George C. Marshall Space Flight Center with Mr. Harold Perkins, R-P&VE-MCA, contracting officer's technical representative acting as project manager.

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ABSTRACT

This second quarterly report on activities of the Cryogenic Data Center reports the progress of the Center's functions and projects during the reporting period. The Documentation Unit issued thirteen weekly lists containing a total of 1134 items of current literature of cryogenic interest. A total of 2429 documents were procured in either full size copy or microform. There were 1975 new entries made into the storage and retrieval system; of these, 1915 were coded in depth for mechanized retrieval. The system had 28,074 accessions at the end of the reporting period of which 11,788 were for properties of materials. Nine bibliographies were prepared containing an average of 152 items. The Center received and filled 508 orders for a total of 4026 NBS-CD Documents. The Data Compilation Unit's activities cover work on the thermodynamic properties of argon, hydrogen, oxygen, fluorine, and physical equilibria of binary mixtures. A new task for the compilation of thermal conductivity and viscosity is also reported. Progress made by the NBS Statistical Physics Section in the quantum mechanical calculation of the second virial coefficient for hydrogen is briefly described. Also included is a summary of work done by the Thermophysical Properties Research Center at Purdue University on a subcontract for data on eight structural metals and alloys. A listing of all tasks undertaken or planned is given. A list of NBS charts and publications relative to this work is also included.

SECOND QUARTERLY PROGRESS REPORT ON CRYOGENIC DATA CENTER ACTIVITIES

FOR THE PERIOD ENDING JUNE 30, 1965

V. J. Johnson, R. B. Stewart, N. A.Olien

1.0 INTRODUCTION

This is the second in a new series of quarterly reports on activities of the Cryogenic Data Center. The First Quarterly Progress Report for the Period Ending March 31, 1965 (NBS Report 8788) included a description of each of the Center's principal functions and projects and a summary of progress to date on current tasks. This second progress report and future progress reports will give only brief reviews of the tasks in addition to a report of the progress during the reporting period. Those readers that are not familiar with the Cryogenic Data Center, however, are referred to the First Quarterly Progress Report for background information.

The Data Center's activities are managed in two principal units; the Documentation Unit under the direction of Neil Olien (see Section 2.0 of this report), and the Data Compilation Unit under the direction of R. B. Stewart (see Sections 3.0 to 6.0 of this report). The Documentation Unit's basic operation and development is supported from the Bureau's direct appropriation under Project 3150121. Some of the services of this Unit are also reimbursed from other projects and outside sales. The Data Compilation Unit is working under the sponsorship of the National Aeronautics and Space Administration for two projects (3150420 and 3150422) and in participation with the National Standard Reference Data System (project 3150421).

The Documentation Unit's principal activities are: a) to maintain an awareness of current publications and reprints of cryogenic interest, b) to acquire and catalog such literature as needed by the Data Compilation Unit, other laboratory staff, and for completing the Data Center's Files, c) to code the pertinent literature in depth for storage and retrieval, and d) to develop and operate a mechanized bibliographic and indexing service for the comprehensive retrieval of information and data in specific subject areas as needed. This Unit also handles distribution of Cryogenics Division's publications (reprints, reports, charts, etc.) and announces the availability of new material periodically.

The Data Compilation Unit is engaged in the critical evaluation of thermophysical property data from the scientific literature for materials at cryogenic temperatures. The objective is the compilation of extensive tables of property values over wide ranges of temperature and pressure. This Unit is a participant in the National Standard Reference Data System which functions within the NBS Institute for Basic Standards. The Data Compilation Unit is recognized as a national authority for data on the properties of materials at cryogenic temperatures, thus all compilation tasks in this Unit are organized for the compilation of data suitable for entry into the NSRDS. Task organization and procedures are outlined briefly in the first progress report.

2.0 CRYOGENIC DATA CENTER, DOCUMENTATION UNIT

(NBS PROJECT 3150121)

Progress is reported on the following areas of documentation activity: current awareness service, literature acquisition, descriptive cataloging of documents, indexing and coding of document content, mechanized storage and retrieval of selected information, preparation of bibliographies, and announcement and distribution of NBS-Cryogenics Division documents.

2.1 Current Awareness Service

A weekly Current Awareness List is circulated to the laboratory staff and others. During this reporting period thirteen lists were prepared containing a total of 1134 items. The lists are currently distributed to 67 laboratory staff members and 70 others outside the laboratory.

2.2 Literature Acquisition

Literature is acquired through subscriptions to current periodicals and by ordering specific documents both for entry into the storage and retrieval system and for the laboratory staff. The Documentation Unit now receives 86 journals, abstract bulletins, title announcement bulletins, etc. which are reviewed for pertinent literature. During this reporting period 1554 printed documents and 875 documents in microform were ordered.

2.3 Descriptive Cataloging

Standard library practices are utilized in cataloging periodical and report literature. Authority lists are maintained for standard journal abbreviations and corporate report headings. During this reporting period 1975 references were cataloged for entry into the storage and retrieval system.

2.4 Coding and Indexing

The storage and retrieval system uses a coordinate index with some features of the traditional hierarchical index. The field of cryogenics has been divided into nine categories, each of which will have its own thesaurus of indexing terms. A thesaurus for category A-6 (cryogenic processes) has been completed and substantial work has been done on thesauri for categories A-7 (laboratory equipment and instrumentation) and A-8 (cryogenic equipment). The indexing and coding of literature are done by professional staff members, who understand the subject matter in much greater depth than do technical librarians and information analysts employed in the large national systems. During the reporting period, 1915 documents were coded and indexed for entry into the storage and retrieval system.

2.5 Mechanized Storage and Retrieval

The Boulder Laboratories' Central computer facility is used for storing and retrieving the identity of documents containing information and data for cryogenics. The complete catalog citation, characteristic coding of the documents and its contents, and the detailed subject coding is key punched into cards for transfer to magnetic tape. At the present time there are 11,788 references in categories A-2 and A-3 (on properties of materials) available for search; of these 719 were added during this reporting period. The change by the NBS, Boulder Laboratories Central Computation Facility from an IBM 7090 Computer to a CDC 3600 Computer required a number of computer program changes, which were completed during this reporting period.

2.6 Preparation of Bibliographies

Bibliographies in answer to user questions are prepared by searching the magnetic tape for the accession numbers of references which contain the desired information. A flexowriter listing of these references is prepared from individual punched paper tapes containing each citation. The charge for this service is $12.00 per minute of computer time and $0.15 for each reference listed. A typical search of one or two subject areas requires one to two minutes of computer time. During the reporting period nine searches were conducted containing an average of 152 items per search. In addition, one extensive bibliography was prepared containing 2430 references. This bibliography was published as NBS Report 8808[24]*.

2.7 Announcement and Distribution of Publications

Over 500 items of reprints, reports, charts, and data sheets which have evolved from activities of the Cryogenic Laboratory over the past several years are available for sale at a price sufficient to cover cost of printing and handling. During the period of this report 508 orders were filled with 4026 items.

* Superscript numbers refer to references listed in Section 9.0.

3.0 CRYOGENIC DATA CENTER, DATA COMPILATION UNIT

REPORT ON TASKS UNDER NBS PROJECT 3150420

(NASA-SNPO, NASA ORDER R-45)

Progress is reported on thermodynamic properties of argon, property differences of ortho and para hydrogen or mixtures of ortho and para hydrogen, and the quantum mechanical calculation of second virial coefficients for hydrogen. A general survey of the literature on the theory of transport properties has been undertaken, and the data on the viscosity and thermal conductivity of argon is being compiled as the initial task in a new project which will include the viscosity and thermal conductivity of all of the major cryogenic fluids. A collection of data sheets on the properties of fluorine are also being compiled.

3.1 Compilation of Saturation Properties for the Cryogenic Fluids

This task has been inactive during the current reporting period; it is anticipated that later in the year work will be resumed as the work load is reduced on other compilation projects. The preliminary work of a literature search on this subject has been completed and a bibliography of experimental properties of cryogenic fluids at saturation has been published as NBS Technical Note 309[18]. The contents of this document were noted in the First Quarterly Progress Report (NBS Report 8788).

The experimental vapor pressure data for oxygen have been analyzed and an equation determined which will reproduce the experimental vapor pressures within the precision of the data. NBS Report 8753[23] describing the work on the vapor pressure equation for oxygen has been published. This work will be extended later to other cryogenic fluids.

3.2 Thermodynamic Properties of Argon

The task on the thermodynamic properties of argon is assigned to a summer employee who was a graduate student, and who has now received his Ph.D. This task has also been the subject for his dissertation. This dissertation, "Thermodynamic Properties of Argon in the Liquid and Gaseous State for Temperatures from the Triple Point to 300°K with Pressures to 1000 Atmospheres", by Albert Louis Gosman has now been accepted by the State University of Iowa. The dissertation includes a recalculation of the thermodynamic property tables that were issued in NBS Report 8293[14]. This new calculation includes more accurate values in the liquid range, and in particular, in the vicinity of the critical point. Copies of these new thermodynamic property tables for argon may be obtained by writing to Professor J. Merle Trummel, Department of Mechanical Engineering, State University of Iowa, Iowa City, Iowa.

This project will be active again in the next reporting period. The study will be continued to consider some new high pressure liquid data. Consideration will also be given to the possibility of an extension of the liquid properties to the vicinity of the solidus line, and the inclusion of saturated solid and vapor data at low pressures as compiled by W. T. Ziegler, J. C. Mullins, and B. S. Kirk**. With these extensions, it is anticipated that the work on the thermodynamic properties of argon will be published in an NBS series of publications. Temperature-entropy diagrams will also be constructed for argon.

** "Calculation of the Vapor Pressure and Heats of Vaporization and Sublimation of Liquids and Solids, Especially below One Atmosphere Pressure. II. Argon", Technical Report No. 2, Project No. A-460, Engineering Experiment Station, Georgia Institute of Technology, (A report prepared under Contract CST-7238 for the Cryogenics Division, National Bureau of Standards.) June 15, 1962.

3.3 Thermodynamic Properties of Normal and Para Hydrogen

During the current reporting period a compilation has been completed on the property differences of ortho and para hydrogen or mixtures of ortho and para hydrogen and is reported in NBS Report 8812[22]. This compilation presents the results of a comprehensive literature search for ortho and para hydrogen property differences. The objective of this study was to obtain thermophysical property data which could be used to determine the differences in these properties for any mixture of the ortho and para modifications of hydrogen. Properties included are specific heat, velocity of sound, thermal conductivity, density, viscosity, vapor pressure, saturated liquid and saturated vapor densities, and latent heat of vaporization. Pertinent comments regarding experimental methods employed, the pressure and temperature range of the data, and the accuracy of the data are included when available. This compilation has not included a critical examination of the data, and this project will continue with the analysis and critical evaluation of these data, to select the "best values".

The task of compiling property differences, as noted in the above paragraph, is a part of a task which has the objective of compiling the thermodynamic properties of normal and para hydrogen over broad ranges of temperature and pressure. This overall study will include a critical evaluation of all of the experimental data on hydrogen, and the work on ortho-para differences will allow the comparison of data with different ortho-para mixtures. Because of the large amount of very accurate data available for hydrogen, the objective of this task will also include an extensive theoretical study of the properties of hydrogen. (Progress on a quantum mechanical calculations of the properties of hydrogen which is being conducted by the Statistical Physics Section in the NBS Institute for Basic Standards is reported in the following section.) As an additional facet to this task, a study has been undertaken on the temperature scales used by the various laboratories which have reported experimental data on properties of cryogenic fluids in the literature. The objective of this study is to allow conversions to the thermodynamic temperature scale for all of the data in the literature. Because much of the hydrogen data is of extreme precision, these minor corrections may be of significance in the hydrogen study. This study will also facilitate the comparison of data in tasks for the compilation of all thermophysical properties for all the cryogenic fluids.

3.4 Quantum Mechanical Calculations of the Properties of Dilute Hydrogen

In the present reporting period, there has been completed the development and testing of computer programs for the quantum mechanical calculation of the second virial coefficient. For input data, these programs use the phase shifts previously obtained as reported in the last progress report. Calculations for ortho-para hydrogen, assuming a spherical intermolecular potential function of the Lennard-Jones type, have been carried out to verify and extend the work of Cohen, et al. (Physica 22, 791, 1956), who had the most elaborate previous set of calculations. Their parameters have been used for the initial computations and the results compared over the temperature range covered by Cohen, et al. (1.85°K to 37°K), as well as extending the range to 100°K.

Good agreement with their results is noted. However, their values are not accurate to the number of digits estimated by these authors. This is due both to the use of an insufficient number of phase shifts, and to not extending the integration to high enough energies. At 37°K their numbers can be shown to be, at best, only good to a single digit. In these calculations, a Born approximation has been used to sum the phase shifts over all values of the angular momentum quantum number to infinity, and have extended the integration to twice the energy value used by Cohen, et al. At 1.85°K the new results for para hydrogen are lower than that reported by Cohen, et al. by 9 cm^3/ mole (about 0.1%), while at 37°K a change of about 1.6 cm^3/mole was obtained (about 3% change) in the direction of the experimental value of Goodwin, et al. (J. Res. Natl. Bur. Std. 68A, 121, 1964) which is about 6 or 7% lower still. This difference must be attributed to the potential function used, and further investi-

gation will be made for adjusting the Lennard-Jones parameters and evaluating non-spherical terms.

The numerical accuracy of these calculations is believed to be at least to three decimal places (five significant figures) at 37°K. The difference between the values calculated for para and ortho hydrogen is reduced by six orders of magnitude over the temperature range up to 37°K and has fallen to a value of .001 cm^3/mole, just observable in our results, but not in those of Cohen, et al. At higher temperatures (up to 100°K) there is a gradual loss of accuracy in our present results until above 80°K only one decimal place (two digits) is valid. It will be necessary to extend the integration to higher energies to obtain more exact values.

The results of this study, as outlined above, will be printed in an NBS Report. The availability of this report will be announced in a later progress report, and copies will be available through the Cryogenic Data Center.

3.5 Viscosity and Thermal Conductivity of Cryogenic Fluids

During the current reporting period, a task for the compilation of the viscosity and thermal conductivity of the cryogenic fluids has been undertaken. As a preliminary to this study, a bibliography was compiled by the Cryogenic Data Center Documentation Unit, and copies of all documents listed have been ordered. All literature on this subject is being reviewed for additional references on viscosity and thermal conductivity.

The first week of June, two additional staff members were added to the Compilation Unit, and both have been assigned initially to this task. A general survey of the many theories of the transport phenomena for different types of fluids under different experimental conditions has been initiated. The selection of a suitable theory for any particular case is a long task, but a start has been made by considering the simplest case; that of a dilute non quantum gas with a spherically symetrical fore-field. Argon was chosen as this gas. Tables of viscosity and thermal conductivity for argon will be compiled as soon as possible and compared with selective expermental data and with the results of other workers. A compilation of the transport properties of argon in the dense gas and fluid phases and of the other common cryogenic fluids will be made as the theoretical studies progress.

3.6 Thermophysical Properties of Fluorine

During the current reporting period a compilation was undertaken for the thermophysical properties of fluorine. The literature on all thermodynamic and transport properties for fluorine are being reviewed and data sheets are being prepared for each property. These data sheets will include the data sources, pertinent comments on the data available, and tabulations of the data available. There is a paucity of information available on fluorine. However, an attempt will be made to compile all the known information on fluorine in this set of data sheets.

4.0 REPORT ON TASKS UNDER NBS PROJECT 3150421

(NBS-NATIONAL STANDARD REFERENCE DATA SYSTEM)

Some funding has been received from the NSRDS during the past two years, as a supplement to the NASA funding which provides the main support of this project. This funding is used to supplement the activities of the task for the thermodynamic properties of normal and para hydrogen. The activities on this task are described in Section 3.3.

5.0 REPORT ON TASKS UNDER NBS PROJECT 3150422

(NASA-MSFC, GOVERNMENT ORDER H-76797)

Progress is reported on the data compilation tasks for the thermodynamic properties of oxygen, and the thermodynamic properties of argon. A new task has also been undertaken for the compilation of the viscosity and thermal conductivity of the cryogenic fluids. Literature searching and data acquisition on the binary mixtures of oxygen and nitrogen, and binary mixtures of argon and nitrogen is noted. The compilation of data sheets on the thermophysical properties of fluorine has also been initiated as a new task.

5.1 Thermodynamic Properties of Oxygen

The project for the compilation of the thermodynamic properties of oxygen is continuing and has been emphasized during the current reporting period. The issuance of NBS Report 8753[23] on a vapor pressure equation for oxygen is noted in Section 3.1 of this report. An equation for the vapor pressure of oxygen is presented which represents the vapor pressure with an accuracy approximating the precision of the data.

As was noted in the first progress report (NBS Report 8788), there are now available four sets of liquid oxygen density data, two of which are preliminary and acquired by private communication from the experimenters. The four sets of data differ in density by as much as 1½% for isotherms near the critical temperature. During the current reporting period, a study has been completed which results in corrections on three of these data sets, thus making the four data sets concordant. These corrections are based on data for the saturated liquid densities, which have been determined from new measurements made in the NBS Properties of Fluids Section in the NBS Cryogenics Division.

Work has also been initiated to establish the best model, using corresponding states principles, for the prediction of P-V-T values for oxygen. This work will be needed to extend the property data tabulations into pressure and temperature ranges where no measurements are available. Work is also continuing on the establishing of an equation of state to represent the P-V-T data for oxygen for the liquid and vapor states and for temperatures from the triple point to ambient. It is anticipated that an improved equation of state for oxygen will be available within the next few months.

5.2 Thermodynamic Properties of Argon

This task is jointly funded by NBS Project 3150422 and 3150420. A report on progress for this task is contained in the preceding description of tasks for Project 3150420, under Section 3.2.

5.3 Viscosity and Thermal Conductivity of the Cryogenic Fluids

This task is jointly funded by NBS Project 3150422 and 3150420. A report on progress for this task is contained in the preceding description of tasks for Project 3150420, under Section 3.5.

5.4 Physical Equilibria and Related Properties of the Binary Mixtures of Oxygen and Nitrogen, and the Binary Mixtures of Argon and Nitrogen

This task has proceeded with a low priority, and the activities have been confined to literature searching and acquisition of literature.

5.5 Thermophysical Properties of Fluorine

This task is jointly funded by NBS Project 3150422 and 3150420. A report on progress for this task is contained in the preceding description of tasks for Project 3150420, under Section 3.6.

6.0 THERMOPHYSICAL PROPERTIES RESEARCH CENTER, PURDUE UNIVERSITY, NBS SUB-CONTRACT NO. CST-7590

(SUB-CONTRACT ON NBS PROJECT 3150420)

This sub-contract is for detailed literature search for density and transport data, and the evaluation and appraisal of the acquired data for eight metals and the stable oxides of their major constituents. The properties and the metals are listed in the first quarterly progress report (NBS Report 8788) together with a complete description of this task.

The results of the literature search covered during the first quarter is summarized on the following table. During the present quarter, data extraction has been initiated and the following progress is reported:

a) About 1/3 of the available data on thermal conductivity and emissivity have been extracted.

b) About 1/2 of the data on specific heat and all data on density, surface tension, and viscosity have been processed.

There still remains a number of references which have not been received and these will be processed as they arrive.

During the next reporting period the man-year effort will be increased to a six-man-month level thus accelerating the pace for the analysis and correlation of the data.

SUMMARY OF BIBLIOGRAPHIC SEARCH RESULTS GIVING THE NUMBER OF REFERENCES IDENTIFIED

MATERIALS	PROPERTIES							
	Specific Heat	Thermal Conductivity	Density	Thermal Diffusivity	Emissivity	Viscosity	Prandtl No.	Surface Tension
Aluminum Alloy 6061-T-6	3	2	1	0	3	0	0	0
Aluminum Alloy-2219-T852	2	2	0	0	0	0	0	0
Aluminum Alloy-7075-T6	9	13	1	6	3	0	0	0
Inconel X-750	6	18	0	1	6	2	0	0
Titanium Alloy-A110-AT	7	9	0	0	3	0	0	2
Beryllium Alloy	0	2	0	0	0	0	0	0
Stainless Steel 304-A	7	23	0	4	0	0	0	0
Stainless Steel 347	16	36	0	5	14	0	0	0
Al	111	137	8	11	66	43	0	5
Be	62	51	2	4	7	0	0	1
Cr	46	28	2	2	29	0	0	2
Cu	144	194	7	13	84	42	0	16
Fe	107	109	10	9	45	22	0	26
Mg	74	46	1	3	14	7	0	2
Mn	30	6	1	0	8	1	0	0
Ni	104	90	8	10	74	15	1	9
Nb	59	57	3	1	19	2	0	3
Si	43	48	6	3	31	2	0	6
Sn	105	110	7	5	21	72	0	8
Ti	50	39	2	3	12	1	0	8
Zn	78	75	2	3	18	34	0	2
Al_2O_3	67	107	9	12	31	4	0	4
BeO	25	83	3	7	15	3	0	0
Cr_2O_3	6	2	0	0	6	1	0	1
Cu_2O	6	2	0	0	9	1	0	0
CuO	4	6	0	0	7	1	0	0
Fe_2O_3	15	7	1	1	7	0	0	0
FeO	6	1	2	0	3	2	0	0
Fe_3O_4	9	5	0	0	1	0	0	0
MgO	42	62	5	5	39	1	0	1
MnO	14	3	0	0	0	1	0	0
MnO_2	6	1	0	0	0	0	0	0
NiO	9	9	2	1	6	1	0	0
NbO_2	6	0	0	0	0	1	0	0
NbO	4	0	0	0	0	0	0	0
Nb_2O_5	7	0	0	0	1	0	0	0
SiO_2	32	64	4	4	14	19	0	2
SnO_2	5	1	1	0	3	1	0	0
SnO	3	0	0	0	1	0	0	0
TiO_2	12	22	1	0	11	1	0	0
Ti_2O_3	5	0	1	0	0	0	0	0
ZnO	2	12	1	1	11	1	0	0

7.0 SUMMARY CHART OF DATA COMPILATION TASKS

TASK NUMBER	DATA COMPILATION TASK	ANTICIPATED STARTING DATE	DATE TASK WAS INITIATED	DATE INITIATED AND/OR PERCENT COMPLETED: PRELIMINARY BIBLIOGRAPHY COMPILED FROM CDC FILES	LITERATURE SEARCH	LITERATURE PROCUREMENT (as listed in bibliography)	BIBLIOGRAPHY COMPILATION	DATA EXTRACTION AND ORGANIZATION	DATA ANALYSIS AND CORRELATION	DATA PREDICTIONS AND EXTENSIONS	REPORT PREPARATION	REPORT IN EDITORIAL REVIEW OR IN PRESS (date)	PROPERTY DIAGRAMS (numbers refer to diagrams listed in Section C.0)	PUBLICATIONS (numbers refer to references listed in Section 9.0)	ESTIMATED COMPLETION DATE	TASK INACTIVE (date)	TASK COMPLETED (date)
	NBS PROJECT 3150420 (NASA - SNPO, NASA Order R-45)																
1 A	Saturation and Fixed Point Properties of Cryogenic Fluids		1/62			100%	100%	80%	10%					18, 23	11/66		
2 A	Thermodynamic Properties of Argon (also see item 4 C)		1/61			100%	100%	100%	90%	90%				13, 14	9/65		
3 A	Viscosity of Cryogenic Fluids (also see item 12 C)	6/65	5/65	4/65	30%	30%											
4 A	Thermal Conductivity of Cryogenic Fluids (also see item 13 C)	6/65	5/65	4/65	30%	30%								6			
5 A	Physical Equilibria and Related Properties of Binary Systems, including Hydrogen	6/65															
6 A	Physical Equilibria and Related Properties of Binary Systems, including Fluorine	6/65															
7 A	Dielectric Constant of Cryogenic Fluids (also see item 14 C)	1/66	4/65			100%	100%	100%	5%	5%				12		4/64	
8 A	Electrical Resistivity of Pure Metals	6/66															
9 A	Thermodynamic Properties of Fluorine (also see item 5 C)	12/66	5/65	5/65	90%	85%	95%	50%						5			
10 A	Thermodynamic Properties of Air	1/67															
11 A	Surface Tension of Cryogenic Fluids (also see item 15 C)	11/65												4		10/62	
12 A	Thermodynamic Properties of normal and para Hydrogen (also see item 1 B)		1/64	1/64	90%	90%	95%	80%						19†, 22	12/66		
13 A	Thermodynamic Properties of Neon					100%	100%	100%	100%	100%			D-44, 48,49	3, 7, 16, 17			2/65
	NBS PROJECT 3150421 (NBS-NSRDS)																
1 B	Thermodynamic Properties of normal and para Hydrogen (also see item 12 A)		1/64	1/64	90%	90%	90%	80%						19†, 22	12/66		
	NBS PROJECT 3150422 (NASA - MSFC, Government Order H-76737)																
1 C	Thermodynamic Properties of Oxygen		*			100%	100%	100%	80%	70%			D-45†	2†, 10†, 15†, 23	8/65		
2 C	Thermodynamic Properties of Nitrogen	6/66															
3 C	Thermodynamic Properties of Helium	10/66												1†			
4 C	Thermodynamic Properties of Argon (also see item 2 A)		*			100%	100%	100%	90%	90%				13†, 14†	9/65		
5 C	Thermodynamic Properties of Fluorine (also see item 9 A)		5/65	5/65	85%	85%	95%	50%						5†			
6 C	Binary Mixtures of O_2 and N_2		2/65	1/65	90%	80%		30%									
7 C	Binary Mixtures of A and N_2		2/65	1/65	90%	80%		30%									
8 C	Binary Mixtures of O_2 and He	6/66															
9 C	Binary Mixtures of N_2 and He	6/66															
10 C	Binary Mixtures of H_2 and He	6/66															
11 C	Binary Mixtures of F_2 and He	6/66															
12 C	Viscosity of O_2, N_2, He, A, and F_2 (also see item 3 A)	6/65	5/65	4/65	30%	30%											
13 C	Thermal Conductivity of O_2, N_2, He, A, and F_2 (also see item 4 A)	6/65	5/65	4/65	30%	30%								6†			
14 C	Dielectric Constant of O_2, N_2, He, A, and F_2 (also see item 7 A)	1/66	*			100%	100%	100%	5%	5%				12†		4/64	
15 C	Surface Tension of O_2, N_2, He, A, and F_2	11/65	*											4†		10/62	
16 C	Electrical Properties of O_2, N_2, He, A, and F_2	9/65															

*task initiated previously with funding from another source

† publications from other projects

8.0 THERMODYNAMIC PROPERTY CHARTS*

Fluid	Number†	Coordinates	Range	Data Source††	Date Issued
Helium	D-3	T-S	20 to 300°K, 0.1 to 100 atm	[1]	June 1961
	D-52	T-S	15 to 300°K, 0.1 to 100 atm	NBS Tech Note 154	Jan. 1964
	D-53	T-S	3 to 25°K, 0.5 to 100 atm	"	"
	D-54	H-S	3 to 25°K, 1.0 to 100 atm	"	"
	D-13	P-Z	20 to 300°K, 1.0 to 100 atm	[1]	Feb. 1961
Parahydrogen	D-20A‡	T-S	20 to 100°K, 1.0 to 340 atm	NBS Tech Note 130	Dec. 1961
	D-21A	T-S	80 to 300°K, 1.0 to 100 atm	"	"
	D-22A‡	H-S	20 to 60°K, 1.0 to 340 atm	"	"
(British units)	D-20B‡	T-S	36 to 180°R, 10 to 5000 psia	"	"
"	D-21B	T-S	140 to 540°R, 10 to 1500 psia	"	"
"	D-22B‡	H-S	36 to 112°R, 10 to 5000 psia	"	"
	D-20	T-S	14 to 100°K, 0.1 to 340 atm	NBS Monograph 94	(1965) (in press)
	D-22	H-S	16 to 64°K, 0.3 to 340 atm	"	" "
Normal Hydrogen	D-14	P-Z	16 to 300°K, .08 to 800 atm	WADD TR 60-56**	Jan. 1961
	D-4	T-S	0 to 150°K, 0.6 to 300 atm	NBS - RP 1932	1948
	D-5	T-S	130 to 300°K, 0.8 to 600 atm	"	"
	D-28	T-S	280 to 600°K, 1.0 to 1200 atm	"	"
Neon	D-48-R	T-S	60 to 300°K, 0.1 to 200 atm	[16]	Mar. 1965
	D-49-R	T-S	25 to 80°K, 0.1 to 200 atm	[16]	"
	D-44	P-Z	30 to 300°K, 1.0 to 200 atm	[3]	Sept. 1962
Nitrogen	D-23	T-S	65 to 300°K, 0.1 to 200 atm	NBS Tech Note 129	Jan. 1963
	D-16	P-Z	90 to 300°K, 1.0 to 500 atm	WADD TR 60-56**	Nov. 1960
	D-17	P-Z	90 to 300°K 300 to 3000 atm	"	"
Oxygen	D-45	T-S	54 to 100°K, sat. liquid to 200 atm (liquid phase only)	NBS Report 7671	Jan. 1963
Air	D-18A	P-Z	90 to 300°K, 1.0 to 600 atm	WADD TR 60-56**	Oct. 1960
	D-18B	T-Z	75 to 300°K 1.0 to 1000 atm	"	"
Carbon Monoxide	D-51	T-S	70 to 300°K, 0.1 to 300 atm	[11]	Sept. 1963
	D-50	P-Z	100 to 300°K, 1.0 to 300 atm	[11]	"

* Unless otherwise noted, charts are in metric units.

† May be ordered from the Cryogenic Data Center, NBS, Boulder by this number. Both 8-1/2 x 11" and 17" x 22" sizes available at 10¢ and 25¢ each, respectively.

‡ Superseded by D-20 or D-22

** "A Compendium of the Properties of Materials at Low Temperatures (Phase II)", WADD Technical Report 60-56, Part IV R. B. Stewart and V. J. Johnson, General Editors (Dec. 1961).

†† Numbers in brackets refer to references listed in Section 9.0.

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